

CHAPTER 4

THICKNESS DESIGN OF LAYERED PAVEMENT STRUCTURE

4-1. Alternative methods of design. The thickness design process is the determination of the required thickness for each layer of a pavement system and of the combined thickness of all layers above the subgrade. Its objective is determining the lowest-cost pavement system whose rate of deterioration under traffic loads and environmental conditions will be acceptably low. In seasonal frost areas, the thickness design process must include the studies and analyses required by normal design, and it must also account for the effects of frost action. Two methods are prescribed here for determining the thickness design of a pavement that will have adequate resistance to 1) distortion by frost heave, and 2) cracking and distortion under traffic loads as affected by seasonal variation of supporting capacity, including possible severe weakening during frost-melting periods.

a. Limited subgrade frost penetration method. The first method is directed specifically to the control of pavement distortion caused by frost heave. It requires a sufficient thickness of pavement, base, and subbase to limit the penetration of frost into the frost-susceptible subgrade to an acceptable amount. Included also in this method is a design approach which determines the thickness of pavement, base and subbase necessary to prevent the penetration of frost into the subgrade. Prevention of frost penetration into the subgrade is nearly always uneconomical and unnecessary and will not be used to design pavements to serve conventional aircraft and motor vehicle traffic. For pavements where layers of synthetic insulation are permitted, full protection of the subgrade against freezing may be feasible (app B).

b. Reduced subgrade strength method. The second method does not seek to limit the penetration of frost into the subgrade but determines the thickness of pavement, base, and subbase that will adequately carry traffic loads over the design period of years, each of which includes one or more periods during which the subgrade supporting capacity is sharply reduced by frost melting. This approach relies on uniform subgrade conditions, adequate subgrade preparation techniques, and transitions for adequate control of pavement roughness resulting from differential frost heave.

4-2. Selection of design method. In most cases, the choice of the pavement design method will be made in favor of the one that gives the lower cost. Exceptions dictating the choice of the limited subgrade frost penetration method, even at higher cost, include pavements in locations where subgrade soils are so extremely variable (as, for example, in some glaciated areas) that the required subgrade preparation techniques could not be expected to sufficiently restrict differential frost heave. In other cases, special operational demands on the pavement facility might dictate unusually severe restrictions on

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tolerable pavement roughness, requiring that subgrade frost penetration be strictly limited or even prevented. If use of the limited subgrade frost penetration method is not required, tentative designs must be prepared by both methods for comparison of costs. Also, a tentative design must be prepared following the non-frost-design criteria of EM 1110-3-131 or EM 1110-3-141 since the thickness requirements under non-frost-criteria must be met in addition to the frost design requirements.

4-3. Design for limited subgrade frost penetration - airfields and roads. This method of design for seasonal frost conditions should be used where it requires less thickness than the reduced subgrade strength method. Its use is likely to be economical only in regions of low design freezing index or for pavements for heavy-load aircraft in regions of moderate to high freezing index.

a. The design freezing index should be used in determining the combined thickness of pavement, base, and subbase required to limit subgrade frost penetration. As with any natural climatic phenomenon, winters that are colder than average occur with a frequency that decreases as the degree of departure from average becomes greater. A mean freezing index cannot be computed where temperatures in some of the winters do not fall below freezing. A design method has been adopted, therefore, that uses the average air freezing index for the 3 coldest years in a 30-year period (or for the coldest winter in 10 years of record) as the design freezing index to determine the thickness of protection that will be provided.

b. The design method permits a small amount of frost penetration into frost-susceptible subgrades for the design freezing index year. The procedure is described in the following subparagraphs.

(1) Estimate average moisture contents in the base course and subgrade at the start of the freezing period and estimate the dry unit weight of base. As the base course may in some cases comprise successive layers containing substantially different fines contents, the average moisture content and dry unit weight should be weighted in proportion to the thicknesses of the various layers. Alternatively, the average may be assumed to be equal to the moisture content and dry unit weight of the material in the unbound base course.

(2) From figure 3-4, determine frost penetration a , which would occur in the design freezing index year in a base material of unlimited depth beneath a 12-inch thick rigid pavement or bituminous pavement kept free of snow and ice. Use straight line interpolation where necessary. For rigid pavements greater than 12 inches in thickness, deduct 10 degree-days for each inch of pavement exceeding 12 inches from the design freezing index before entering figure 3-4 to determine frost penetration a . Then add the extra concrete pavement thickness to the determined frost penetration.

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(3) Compute base thickness c (fig 4-1) required for zero frost penetration into the subgrade as follows:

$c = a - p$, where p = thickness of portland cement concrete or bituminous concrete.

(4) Compute ratio $r = \frac{\text{water content of subgrade (ws)}}{\text{water content of base (wb)}}$

(5) Enter figure 4-1 with c as the abscissa and, at the applicable value of r , find in the left scale the design base thickness b that will result in the allowable subgrade frost penetration s shown on the right scale. For airfield runways, if computed r is equal to or exceeds 2.0, use 2.0 in figure 4-1. For other pavements, if r is equal to or exceeds 3.0, use 3.0 in figure 4-1.

c. The above procedure will result in a sufficient thickness of material between the frost-susceptible subgrade and the pavement so that for average field conditions subgrade frost penetration of the amount s should not cause excessive differential heave of the pavement surface during the design freezing index year. The reason for establishing a maximum limit for r is that not all the moisture in fine-grained soils will actually freeze at the subfreezing temperatures that will penetrate the subgrade.

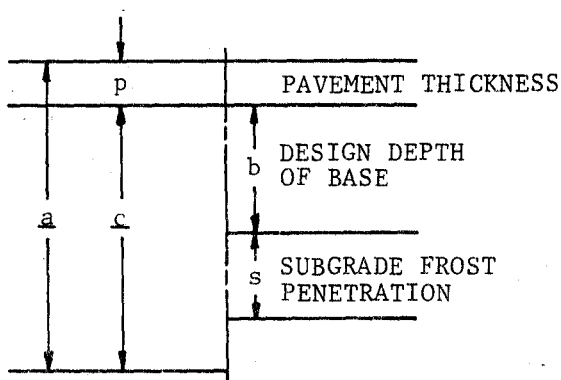
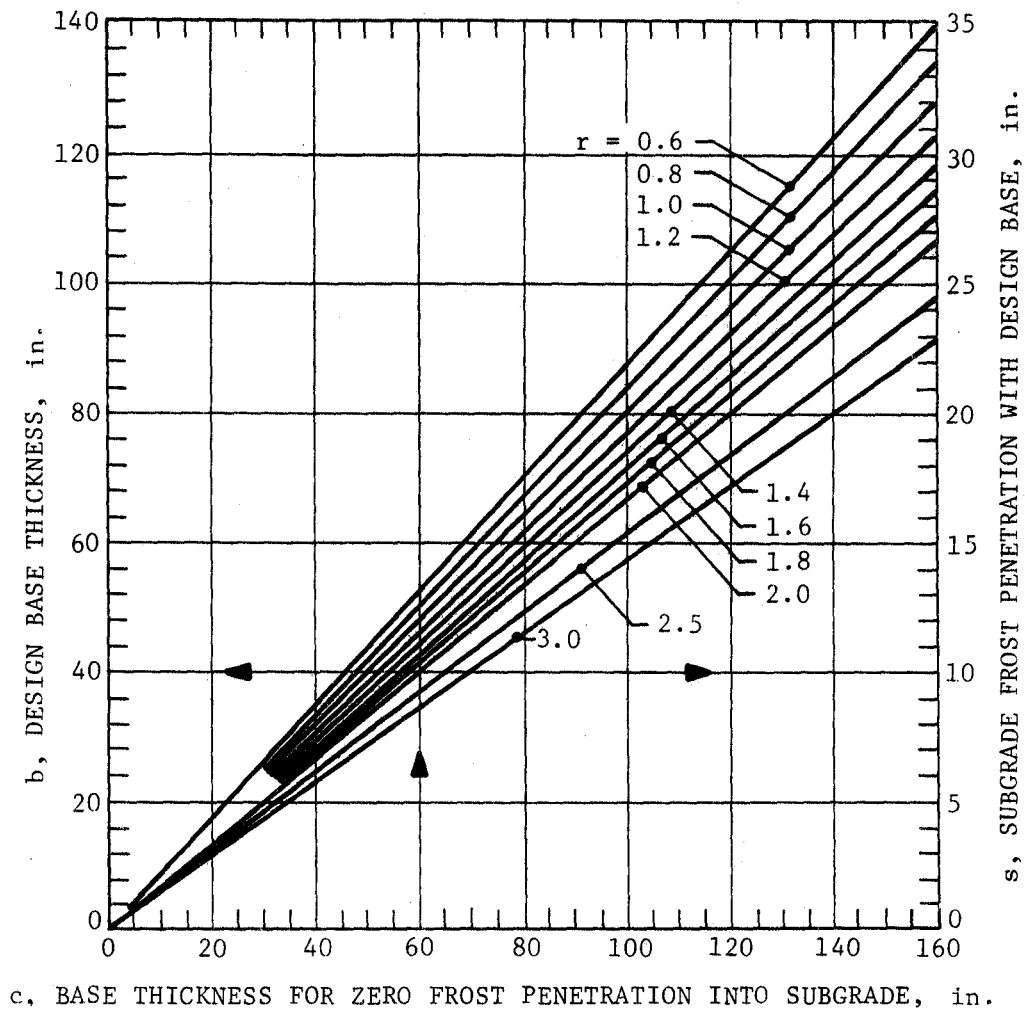
d. When the maximum combined thickness of pavement and base required by this design procedure exceeds 60 inches, consideration should be given to alternatives such as the following:

- Limiting total combined thickness to 60 inches and, in rigid-type pavements, using steel reinforcement to prevent large cracks.
- Limiting total combined thickness to 60 inches and, in rigid-type pavements, limiting the maximum slab dimensions (as to 15 feet) without use of reinforcement.
- Reducing the required combined thickness by use of a subbase of uniform fine sand, with high moisture retention when drained, in lieu of a more free-draining material.

The first two of these alternatives would result in a greater surface roughness than obtained under the basic design method because of greater subgrade frost penetration. With respect to the third alternative, it should be noted that base course drainage requirements of EM 1110-3-136 must still be met.

e. If the combined thickness of pavement and base required by the non-frost-criteria exceeds the thickness given by the limited subgrade

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EXAMPLE: If $c = 60''$ and $r = 2.0$, then
 $b = 40''$ and $s = 10''$

a = Combined thickness of pavement and non-frost-susceptible base for zero frost penetration into subgrade

$c = a - p$

w_b = Water content of base

w_s = Water content of subgrade

$r = \frac{w_s}{w_b}$, Not to exceed 2.0 for Type A and B areas on airfields and 3.0 for other pavements

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FIGURE 4-1: THICKNESS OF NON-FROST-SUSCEPTIBLE BASE FOR LIMITED SUBGRADE FROST PENETRATION

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frost penetration procedure of design, the greater thickness given by the non-frost-criteria will be adopted as the design thickness.

f. The base course composition requirements should be rigorously followed. The design base thickness determined is the total thickness of filter layers, granular unbound base and subbase, and any bound base. The thickness of the asphalt surfacing layer and of any bound base, as well as the CBR (California Bearing Ratio) requirements of each layer of granular unbound base, will be determined as set forth in EM 1110-3-131 and EM 1110-3-141. The thickness of rigid pavement slab will be determined from EM 1110-3-132 and EM 1110-3-142.

4-4. Design for reduced subgrade strength - airfields and roads. Thickness design may also be based on the seasonally varying subgrade support that includes sharply reduced values during thawing of soils that have been affected by frost action. Excepting pavement projects for heavyload aircraft or those that are located in regions of low design freezing index, this design procedure usually requires less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for both flexible and rigid pavements wherever the subgrade is reasonably uniform or can be made reasonably horizontally uniform by the required techniques of subgrade preparation. This will prevent or minimize significant or objectionable differential heaving and resultant cracking of pavements. When the reduced subgrade strength method is used for F4 subgrade soils, unusually rigorous control of subgrade preparation must be required. When a thickness determined by the reduced subgrade strength procedure exceeds that determined for limited subgrade frost penetration, the latter, smaller value should be used, provided it is at least equal to the thickness required for non-frost-conditions. In situations where use of the reduced subgrade strength procedure might result in objectionable frost heave, but use of the greater thickness of base course indicated by the limited subgrade frost penetration design procedure is not considered necessary, intermediate design thicknesses may be used. However, these must be justified on the basis of frost heaving experience developed from existing airfield and highway pavements where climatic and soil conditions are comparable.

a. Thickness of flexible pavements. In the reduced subgrade strength procedure for design, the curves in EM 1110-3-141 should be used to determine the combined thickness of flexible pavement and base required for aircraft wheel loads and wheel assemblies, and the design curves of EM 1110-3-131 should be used for highway and parking area design. In both cases, the curves should not be entered with subgrade CBR values determined by tests or estimates but instead with the applicable frost-area soil support index from table 4-1. Frost-area soil support indices are used as if they were CBR values; the term CBR is not applied to them, however, because, being weighted average values for an annual cycle, their value cannot be determined by CBR tests.

(1) General field data and experience indicate that on the relatively narrow embankments of highways, reduction in strength of subgrades during frost melting may be less in substantial fills than in cuts because of better drainage conditions and less intense ice segregation. If local field data and experience show this to be the case, then a reduction in combined thickness of pavement and base of up to 10 percent may be permitted for highways on substantial fills.

(2) EM 1110-3-141 and EM 1110-3-131 should also be used to determine the thicknesses of individual layers in the pavement system and to ascertain whether it will be advantageous to include one or more layers of bound base in the system.

Table 4-1. Frost-area Soil Support Indices for Flexible Pavement Design

Frost group of subgrade soil	F1	F2	F3 and F4
Frost-area soil support index	9.0	6.5	3.5

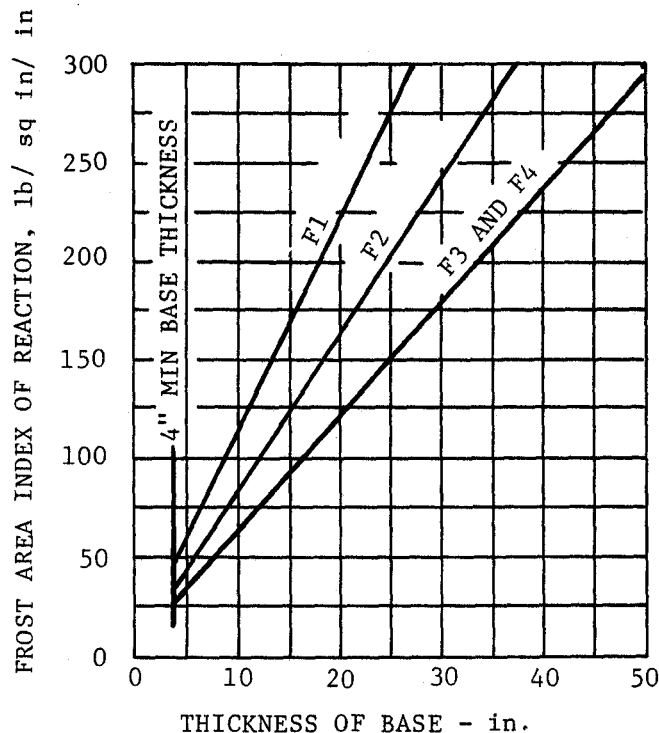
b. Thicknesses of rigid pavements. Where frost is expected to penetrate into a frost-susceptible subgrade beneath a rigid pavement, it is good practice to use a non-frost-susceptible base course at least equal in thickness to the slab. Experience has shown, however, that rigid pavements with only a 4-inch base have performed well in cold environments with relatively uniform subgrade conditions. Accordingly, where subgrade soils can be made reasonably uniform by the required procedures of subgrade preparation, the minimum thickness of granular unbound base should be 4 inches.

(1) Additional granular unbound base course, giving a thickness greater than the minimum specified above, will improve pavement performance, giving a higher frost-area index of reaction on the surface of the unbound base (fig 4-2) and permitting a pavement slab of less thickness. Bound base also has significant structural value and may be used to effect a further reduction in the required thickness of the pavement slab. EM 1110-3-142 and EM 1110-3-132 establish criteria for determination of the required thickness of rigid pavement slabs in combination with a bound base course. The provisions presented herein comprising requirements for granular unbound base as drainage and filter layers will still be applicable.

(2) The thickness of concrete pavement will be determined in accordance with EM 1110-3-142 for airfields and EM 1110-3-132 for roads and parking areas, using the frost-area index of reaction determined from figure 4-2. This figure shows the equivalent weighted average index of reaction values for an annual cycle that includes a period of thaw-weakening in relation to the thickness of base. Frost-area indices of reaction are used as if they were moduli of reaction, k , and have the same units. The term modulus of reaction is not applied to

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT
F2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT
F3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS

NOTE: FOR DESIGN OVER F4 SUBGRADE SOILS SEE TEXT



FROST CONDITION REDUCED SUBGRADE STRENGTH DESIGN SUBGRADE MODULUS CURVES FOR RIGID AIRFIELD AND HIGHWAY PAVEMENTS

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FIGURE 4-2. FROST-AREA INDEX OF REACTION FOR DESIGN OF RIGID AIRFIELD AND HIGHWAY PAVEMENTS

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them, however, because being weighted average values for an annual cycle, they cannot be determined by a plate-bearing test. If the modulus of reaction, k , determined from tests on the equivalent base course and subgrade, but without frost melting, is numerically smaller than the index of reaction obtained from figure 4-2, the test value should govern the design.

4-5. Design of flexible pavement for runway overruns.

a. Frost condition requirements. A runway overrun pavement must be designed to withstand occasional emergency aircraft traffic in the form of short or long landings, aborted takeoffs, and possible barrier engagements. The pavement must also serve various maintenance vehicles such as crash trucks and snowplows. The design of an overrun must provide:

- Adequate stability for very infrequent aircraft loading during the frost-melting period.
- Adequate stability for normal traffic of snow-removal equipment and possibly other maintenance vehicles during frost-melting periods.
- Sufficient thickness of base or subbase materials of low heave potential to prevent unacceptable roughness during freezing periods.

b. Overrun design for reduced subgrade strength. To provide adequate strength during frost-melting periods, the flexible pavement and base course shall have the combined thickness given by the design curves in EM 1110-3-141 enter the curves with the applicable frost-area soil support index given in table 4-1. The thickness established by this procedure should have the following limitations:

- It should not be less than required for non-frost-condition design in overrun areas, as determined from EM 1110-3-141.
- It should not exceed the thickness required under the limited subgrade frost penetration design method.
- It should not be less than that required for normal operation of snowplows and other medium to heavy trucks.

The subgrade preparation techniques and transition details of this manual are required for overrun pavements. The composition of the layered pavement structure should conform with the applicable requirements of EM 1110-3-141, except that the composition of base courses should also conform with the requirements of this manual.

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c. Overrun design for control of surface roughness. In locations with low to moderate design freezing indices, thicknesses smaller than those required by the reduced strength method may be given by the limited subgrade frost penetration method of design. If this happens, the latter should be used, but in no case will combined thicknesses smaller than those given for non-frost-design by EM 1110-3-141 be adopted. On the other hand, in some instances, local experience may indicate that a design thickness determined by the reduced subgrade strength method, coupled with the required subgrade preparation procedures and transitions will not restrict maximum differential frost heave to an amount which is reasonable for these emergency areas, generally not more than about 3 inches in 50 feet. In the selection of a design for restricting frost heave, consideration must be given to type of subgrade material, availability of water, depth of frost penetration, and local experience. Guidance is provided in the following subparagraphs.

(1) For a frost group F3 subgrade, differential heave can generally be controlled to 3 inches in 50 feet by providing a thickness of base and subbase course equal to 60 percent of the thickness required by the limited subgrade frost penetration design method.

(2) For well-drained subgrades of the F1 and F2 frost groups, lesser thicknesses are satisfactory for control of heave. However, unless the subgrade is non-frost-susceptible, the minimum thickness of pavement and base course in overruns should not be less than 40 percent of the thickness required for limited subgrade frost penetration design.

(3) The criteria set forth for control of surface roughness apply only if they require a combined pavement and base thickness in excess of that needed for adequate load supporting capacity.

4-6. Design of shoulder pavements.

a. Pavement thickness design and composition of base courses. Where paved shoulders are required on airfields, the flexible pavement and base should have the combined thickness given by the design curve in EM 1110-3-141; enter the curve with the applicable frost-area soil support index shown in table 4-1. If the subgrade is highly susceptible to heave, local experience may indicate a need for a pavement section that incorporates an insulating layer or for additional granular unbound material to moderate the irregularity of pavement deformations resulting from frost heave.

b. Control of differential heave at small structures located within shoulder pavements. To prevent objectionable heave of small structures inserted in shoulder pavements, such as drain inlets and bases for airfield lights, the pavement substructure, extending at least 5 feet radially from them, should be designed and constructed entirely with

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non-frost-susceptible base and subbase course materials of sufficient thickness to prevent subgrade freezing. Gradual transitions are required. Alternatively, synthetic insulation could be placed below a base of the minimum prescribed thickness to prevent the advance of freezing temperatures into the subgrade; suitable transitions to the adjoining uninsulated pavement would be needed.

4-7. Use of state highway requirements for roads, streets, and open storage areas. To provide further flexibility in design options and to exploit economical local materials and related experience, state highway requirements may be used for pavements with a design index less than 4. Design index is defined in EM 1110-3-131 and EM 1110-3-132. The decision to use local state highway requirements will be based on demonstrated satisfactory performance of pavements in that state as determined by observation and experience. This should give reasonable assurance that the life cycle cost resulting from use of state highway requirements is comparable to that from use of Corps of Engineers criteria and procedures. If state requirements are used, the entire pavement should conform in every detail to the applicable state criteria.